Balloon-Borne Video Cassette Recorders For Digital Data Storage

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1. Introduction

A high-speed, high-capacity digital data storage system has been developed for a new balloon-borne γ-ray telescope (see paper OG9.2-2). The system incorporates sophisticated, yet easy to use and economical consumer products: the portable video cassette recorder (VCR) and a relatively newer item - the "digital audio processor". The in-flight recording system employs eight VCRs and will provide a continuous data storage rate of 1.4 megabits/sec throughout a 40 hour balloon flight. Data storage capacity is 25 gigabytes and power consumption is only 10 watts.

2. The Digital Audio Processor

The key to rapid development of a VCR based digital data storage system was the availability of the digital audio processor, a consumer product intended to allow the use of a home VCR as a digital audio tape recorder. A simplified block diagram of such a processor, the Sony PCM-701ES is shown in Figure 1. In normal stereo recording operation the incoming left and right audio signals are each digitized with 16 bit resolution at a rate of 44 kHz. The digital data are multiplexed onto a single serial line and input to the "record data processor" at a rate of 1.4 megabits/sec. The processor adds error detecting and correcting codes, interleaves the data, and finally generates a video signal in standard NTSC television format suitable for recording on any home VCR. On playback the digital data are unscrambled, corrected for errors, and sent to 16 bit DACs which reconstruct the original audio waveforms. The powerful "cross interleaved" error correction scheme [1,2] virtually eliminates errors due to dropouts on the VCR tape, as is required for noise-free audio reproduction.

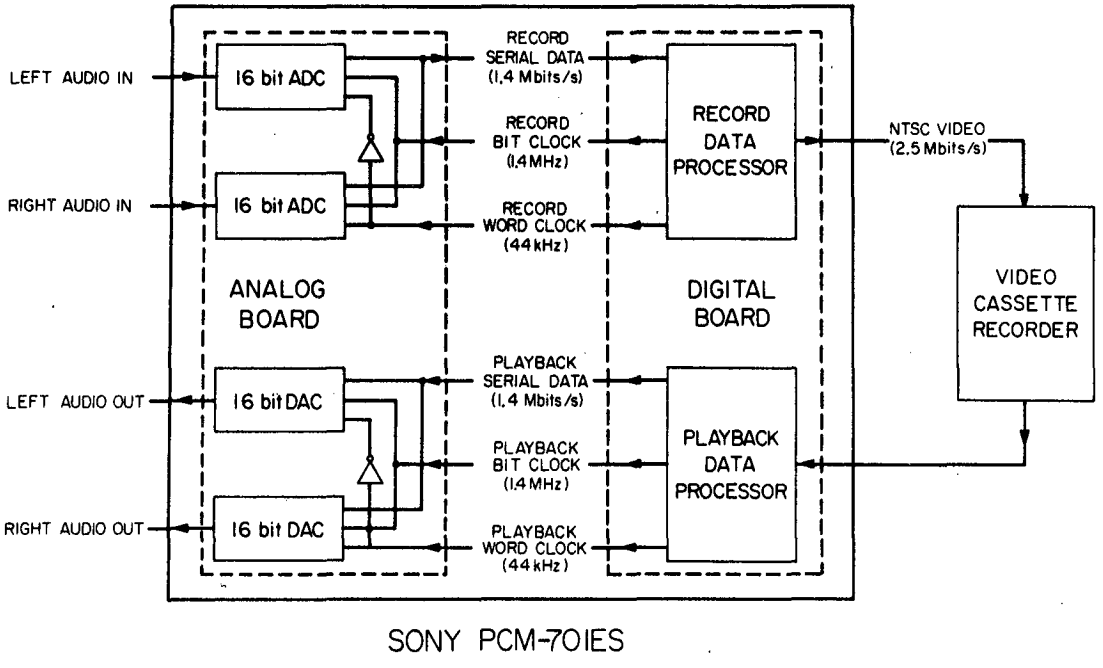

Figure 1. Simplified block diagram of the Sony PCM-701ES Digital Audio Processor.

As shown in Figure 1, the circuitry within the Sony PCM-701ES is conveniently divided into two main printed circuit boards - an analog board and a digital board. For our purpose only the digital board is required. It has been incorporated in our flight recording system (Figure 2) and as part of a record/playback computer peripheral (Figure 3). The digital board is very easy to use. It operates from a single 5 volt supply, is TTL compatible and provides standard 75 ohm video input and output. Power consumption is 3 watts.

The Sony PCM-701ES may be operated in either a 14 or 16 bit mode. In the 16 bit mode the full resolution of the 16 bit ADCs and DACs are used, but fewer error correcting bits are encoded. In the 14 bit mode tape dropouts of up to 32 horizontal television scan lines can be perfectly corrected, while in the 16 bit mode error correction is guaranteed only for dropouts of up to 16 lines [3]. Nonetheless, for the convenience of a simple 16 bit word-aligned format we have used the 16 bit mode. As discused below, the error rate is quite low when high-quality tape is used.

3. Application

In our balloon flight application, γ-ray event data are written into a 2K byte buffer memory while a second buffer memory is read into the PCM-701ES digital board in the format described below. Each buffer can hold 63 events, and buffers are switched synchronously every 11.7 msec, slaved to the PCM-701ES data clock. Thus, ~5400 events per second can be recorded with no deadtime, while the PCM-701ES is supplied with a continuous data stream of 1.4 megabits/sec. The NTSC video signal is fed to eight Sony SL2000 portable VCRs, which are operated sequentially with a capacity of 5 hours recording time for each VCR. Data capacities are summarized in Table I.

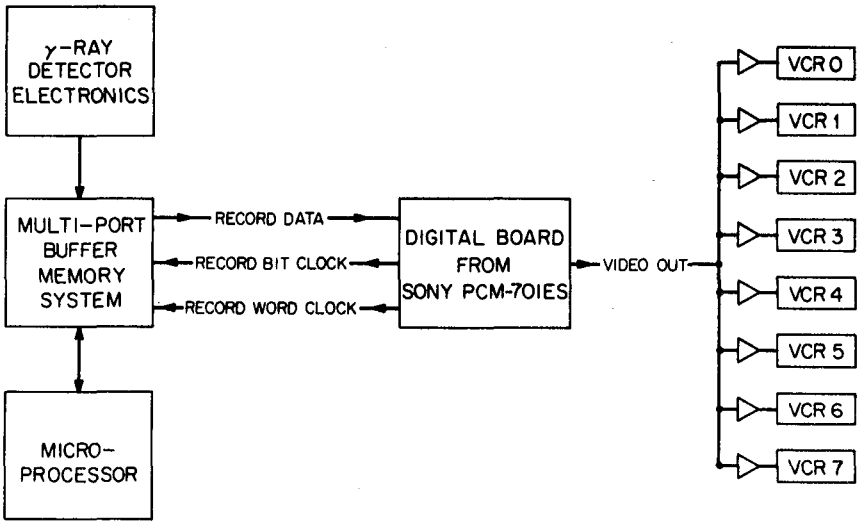

Figure 2. Block diagram illustrating the use of the Sony PCM-701ES digital board in a balloon-borne data recording system.

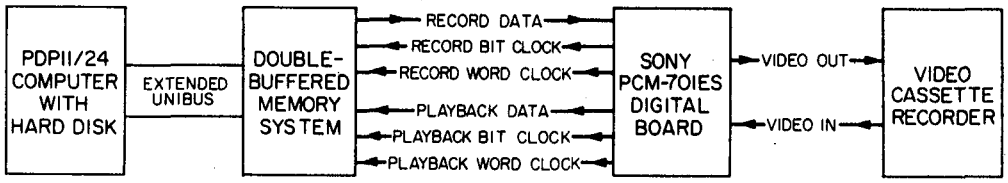

Figure 3. Block diagram showing the Sony PCM-701ES digital board as part of a mass storage computer peripheral.

Table 1. Balloon-Borne γ-ray Telescope Data Storage System	
Data Rate	1.4×10^6 bits/sec 175,000 bytes/sec 5400 events/sec
Recording Time (per tape) (total)	 5 hrs 40 hrs (8 VCRs)
Data Capacity (per tape) (total)	 2.5×10^{10} bits 3.2×10^9 bytes 9.7×10^7 events 2×10^{11} bits 2.5×10^{10} bytes 7.8×10^8 events
Power Consumption Digital board Portable VCR (total)	 3 watts 7 watts 10 watts

We have measured the error rate using Sony L750 Ultra High Grade tape recorded at "βIII" speed on Sony SL2000 portable VCRs. In initial tests approximately 1.5 million 2K byte data blocks were recorded on each of seven video cassettes using seven different VCRs (21 gigabytes total). Each data block contained a 32 bit start code, a 32 bit block count, approximately 1000 psuedo-random 16 bit numbers, a 32 bit stop code and a 16 bit cyclic redundancy check (CRC) code. The tapes were played back on a single VCR and each data block was checked for an accurate start and stop code, CRC error, and sequential block count. Of the 10.5 million blocks checked ~300 were missing (due to "playback muting", where the PCM-701ES simply replaced long stretches of uncorrectable data with a fixed data word), and 19 CRC errors were detected (due to "playback interpolation" where the PCM-701ES replaced isolated uncorrectable data words with the average of adjacent words). The fraction of blocks discarded due to detected errors was $\sim 3 \times 10^{-5}$, a negligible data loss rate for most data acquisition applications. A sample of 600,000 "good" blocks were checked 100% for undetected errors and none were found. Thus the undetected block error rate was less than 2×10^{-6}, acceptable for our present application.

The VCR data systems discussed here were used to record and playback data for the formation of the γ-ray images presented in paper OG9.2-2. In this process 56 megabytes of data were recovered without a single detected error.

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4. References

[1] Doi, T.T., Odaka, K., Fukuda, G., Furukawa, S., "Cross Interleave Code for Error Correction of Digital Audio Systems", Audio Engineering Society Preprint, 1979.

[2] Doi, T.T., Tsuchiya, Y., and Iga, A., "On Several Standards for Converting PCM Signals into Video Signals", *J. Audio Eng. Soc.*, **26-9**, pp. 641-649, 1978.

[3] Sony PCM-701ES Operating Instructions, 1983.